Tropical Cyclone Formation/Structure/Motion Studies

Patrick A. Harr
Department of Meteorology
Naval Postgraduate School
Monterey, CA 93943-5114
phone: (831) 656-3787 fax: (831) 656-3061 email: paharr@nps.edu

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LONG-TERM GOALS

The long-term goals are to understand how variabilities in the large-scale atmospheric environment influence tropical cyclone track, structure, and intensity characteristics, and define how these influences differ between developing, mature, and decaying tropical cyclones. Throughout its life cycle, a tropical cyclone has the potential for impacting many shore- and sea-based fleet operations. During the intensification stage of a tropical cyclone, structure and track characteristics can exhibit large variabilities that decrease potential predictability. Furthermore, there are often periods of reduced predictability during the decaying stage of a tropical cyclone. Because decaying tropical cyclones often transitions to a fast-moving and rapidly-developing extratropical cyclone that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition (ET) phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns. Furthermore, the ET of a tropical cyclone may impact the midlatitude circulation patterns downstream.

OBJECTIVES

Primary objectives relate to the predictability associated with tropical cyclone formation and extratropical transition. The ability of operational global numerical forecast models to predict the formation of a tropical cyclone is examined. The goal is to provide guidance that conveys a forecast confidence as to whether a specific tropical disturbance will intensify into a tropical cyclone. Structural changes in a mature tropical cyclone are examined as the tropical cyclone moves poleward and begins the ET process. The impacts on predictability are assessed in terms of the increased variability that is introduced into the midlatitude circulation by the ET event and with respect to the predictability associated with the downstream impacts of the ET. The goal is to determine specific aspects of ET that are least predictable by examining forecast characteristics that are most inconsistent among multiple integrations of several operational global numerical models and global model ensemble forecast systems. Also, the structural evolution of the decaying tropical cyclone as it transitions from a tropical to extratropical cyclone is examined to identify important environment conditions associated with an ET that may impact operational forecasts of the environmental conditions related to maritime operations near an ET event.

APPROACH

Forecasts of tropical vortices made by the National Centers for Environmental Prediction Global Forecast System (GFS), the United States Navy Operational Global Atmospheric Prediction System (NOGAPS), and the United Kingdom Meteorological Office Global Model (UKMO) are analyzed with respect to physical quantities that are relevant to tropical cyclone formation. While summarizing statistics such as false alarm rates and probability of detection are readily identifiable from the database, the potential for correct forecasts of tropical cyclone formation in each model is assessed. A comprehensive database of analyzed and forecast values of physically-relevant parameters associated with tropical cyclone formation continues to be updated. Tropical vortices that occurred over the western North Pacific, eastern North Pacific, and North Atlantic basins are contained in the database. The set of fourteen parameters is subjected to a statistical analysis intended to identify the potential for intensification of a tropical vortex to a tropical cyclone. A probabilistic framework is followed. This type of analysis is made possible by the objective identification and catalog of model parameters relevant to each tropical vortex. This procedure allows for continuous assessment of model performance with respect to a variety of parameters and vortices. Based on the comprehensive database, the discriminant analysis is able to consolidate a comprehensive set of parameters for the purpose of assessing the development potential given the forecast associated with each new tropical vortex. A comparison of each model's ability to correctly identify tropical vortices that develop into a tropical cyclone will be presented.

The poleward movement and extratropical transition (ET) of a tropical cyclone (TC) initiates complex interactions with the midlatitude environment that often results in a high-impact midlatitude weather system with strong winds, high seas, and large amounts of precipitation. Although these extreme conditions severely impact the region of the ET, there are significant impacts downstream of the ET event due to the excitation of large-scale propagating Rossby wave-like disturbances. The approach to the primary scientific issues associated with ET and downstream impacts due to ET events is to define a framework of mechanisms, predictability, and strategies for increasing predictability. The ET process is often associated with a decrease in forecast skill of operational global numerical weather prediction models (Fig. 1). To understand the impact of ET on high-impact downstream weather events, mechanisms responsible for the generation, intensification, and propagation of Rossby wave-like disturbances that often form during ET events (Fig. 2). A Rossby wave response may be forced by advection of vorticity due to the divergent wind, which may result from the tropical cyclone core. A similar mechanism may be associated with diabatic Rossby waves due to upward motion along sloping isentropic surfaces that exist at the tropical cyclone-midlatitude interface. Data from polar-orbiting satellites have been utilized to provide a representation of the structural evolution of the thermal, wind, and precipitation fields during an ET event. A representative ET case (TY Nabi in Figs 1 and 2) was chosen in a pilot study of the structural changes associated with ET and the dispersion of energy downstream across the North Pacific.

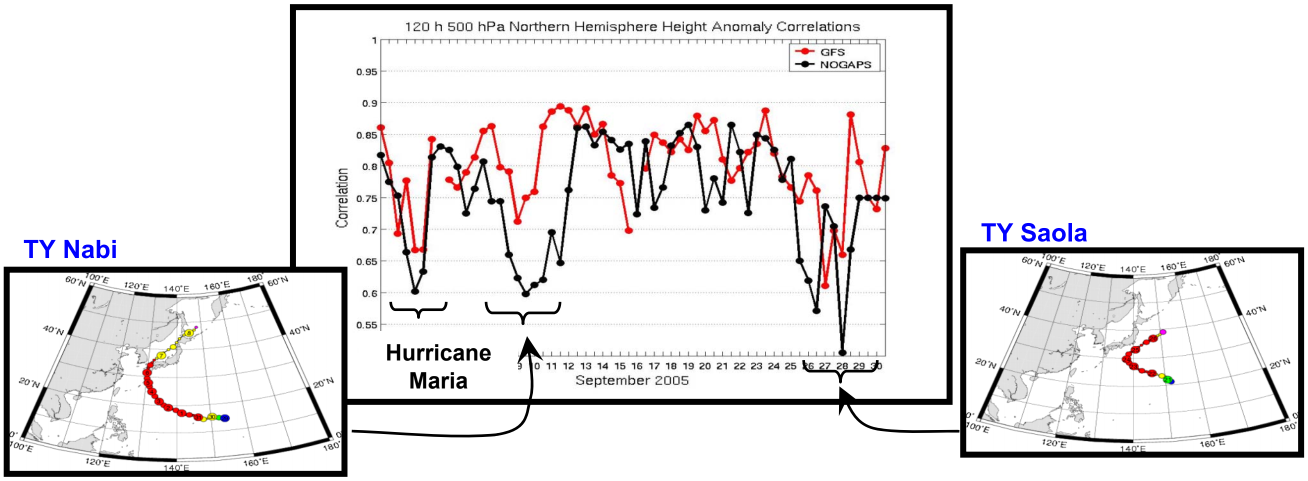

Figure 1: Height anomaly correlations over the Northern Hemisphere for 120-h forecasts from the GFS and NOGAPS models during September 2005. Periods of low correlation values that coincide with the ET of tropical cyclones are labeled. Tropical cyclone track figures courtesy of http://agora.ex.nii.ac.jp/digital-typhoon/

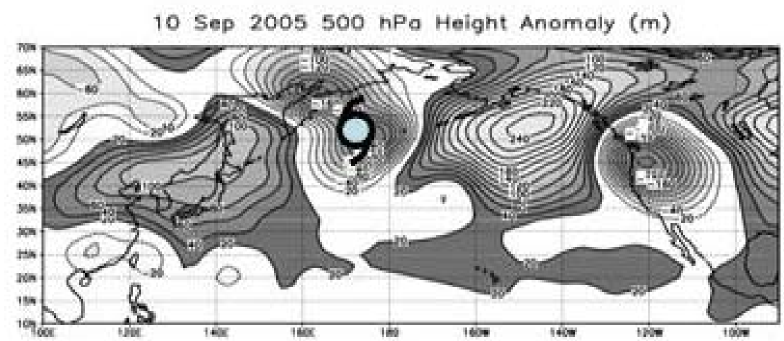

Figure 2: Daily 500 hPa height anomalies (m) for 10 September 2005. The location of TY Nabi is marked by the tropical cyclone symbol.

WORK COMPLETED

A diagnostic analysis of the extratropical transition of Typhoon (TY) Nabi (July, 2005) was performed. In this analysis, a combination of numerically-analyzed fields and data from polar-orbiting satellites was used to examine the changes in structural characteristics of the decaying tropical cyclone. The predictability associated with the ET of Nabi was examined using the ensemble prediction system (EPS) from the GFS operational global forecast model (Harr et al. 2007). The predictability associated with TY Nabi was compared with predictability associated with other ET cases over the western North Pacific and North Atlantic (Anwender et al. 2007). Furthermore, the impact on the downstream midlatitude synoptic-scale circulations was assessed in association with the downstream energy dispersion during the ET of TY Nabi (Dea 2007, Harr and Dea 2007).

RESULTS

The ET of TY Nabi (September, 2005) was associated with a sharp decrease in forecast accuracy associated with the GFS model and the Navy Operational Global Atmospheric Prediction System (NOGAPS) (Fig. 1). The low height anomaly correlation scores were due to forecasts that did not contain the Rossby wave-like response associated with TY Nabi (Fig. 2). Furthermore, standard deviation among ensemble members from the GFS EPS exhibited relative maxima associated with the circulation centers that spread downstream of the ET event (Fig. 3).

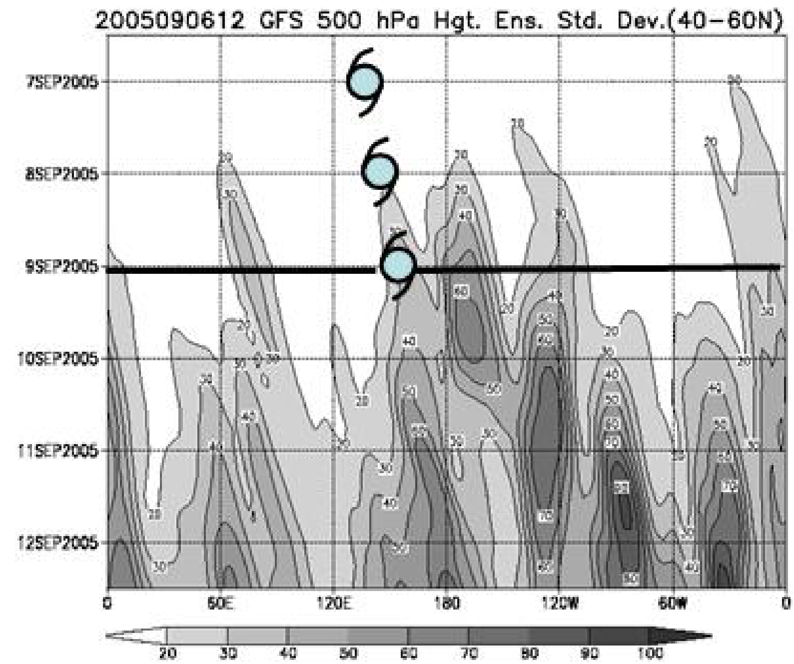

Figure 3: Time-longitude plot of 500 hPa height standard deviation (m) for the GFS ensemble prediction system members initialized at 1200 UTC 6 September 2005. The standard deviation is averaged between 40°N – 60°N. Beginning at 0000 UTC 7 September, the tropical cyclone symbols identify the longitudinal position of TY Nabi. The thick black line at 0000 UTC 9 September marks the time that TY Nabi was declared extratropical and the time at which the cluster analysis was applied to the principal components.

A pronounced Rossby wave-like response propagated downstream of Nabi in association with a large mid- to upper-tropospheric anticyclone that formed immediately east of the decaying tropical cyclone. The thermodynamic and dynamic mechanisms associated with the formation of this anticyclone were examined using analyzed potential vorticity fields and temperature data derived from polar-orbiting satellites (Dea 2007). In association with the circulations that developed downstream of the ex-Nabi (Fig. 2), corresponding maxima in standard deviation among ensemble members developed (Fig. 3). A fuzzy cluster analysis (Harr et al. 20007) was applied to the ensemble members to identify the set of possible scenarios associated with the evolution of the synoptic-scale flow that was contributing to the maxima in standard deviation. As the forecast initiation time approached the time of ET, the centers of maximum standard deviation decreased as the evolution of the synoptic-scale flow over the North Pacific became more predictable. Anwender et al. (2007) applied a similar analysis to a set of ET cases over the western North Pacific and North Atlantic using the EPS of the European Center for Medium Range Weather Prediction (ECMWF). Similar evolution of the standard deviation among ensemble members was found, which defines the impact of ET events on the predictability associated with the ECMWF operational global forecast system.

To examine the impact of ET events on the development of synoptic scale flow across the North Pacific, Harr and Dea (2007) examined the dispersion of energy over the North Pacific from mid-July to the end of September 2005 (Fig. 4). Often, the movement of a tropical cyclone poleward of 40^{o}N resulted in the subsequent increase in kinetic energy across the North Pacific. As TY Nabi began ET, the flux of eddy kinetic energy from the ex-Nabi into a developing trough south of the Kamchatka Peninsula increased (Fig. 5). An energy budget was computed to define the relative contributions to the transport of energy downstream from the ET event. Once the trough near the central North Pacific developed, additional transport of eddy kinetic energy occurred toward the eastern North Pacific. Based on the time series of eddy kinetic energy in Fig. 4, this pattern occurred in relation to several ET events during the summer of 2005. Therefore, the ET of tropical cyclones has a major impact on the distribution of eddy kinetic energy over the entire North Pacific basin.

IMPACT/APPLICATIONS

As characteristics and identification of the predictability associated with operational forecast model characteristics with respect to ET become identified, guidance to operational forecasters will be available such that increased value from numerical products will be realized. Finally, accurate probabilistic forecasts of tropical cyclone formation conditioned on parameters that are analyzed and forecast by operational global models will provide for increased utility for long-range planning of operations in regions over which tropical cyclones tend to form.

TRANSITIONS

It is anticipated that an operational forecast scheme of probabilistic prediction of tropical cyclone formation could be automated via interaction with the database of model forecast parameters. An assessment of the potential for accurate forecasts with respect to ET circulations will be available to operational forecasters. Systematic examination of microwave data during the ET of tropical cyclones will lead to use of a pattern analysis by forecasters to diagnose the important structural changes during the ET process. The identification of factors associated with ET that impact downstream development will be implemented as forecast aids to identify synoptic-scale flow patterns at medium-range intervals (i.e., 3-7 days).

RELATED PROJECTS

The work being completed on the structural changes and downstream impacts during ET is related to a project titled The predictability of extratropical transition and of its impact on the downstream flow under the direction of Dr. Sarah Jones.

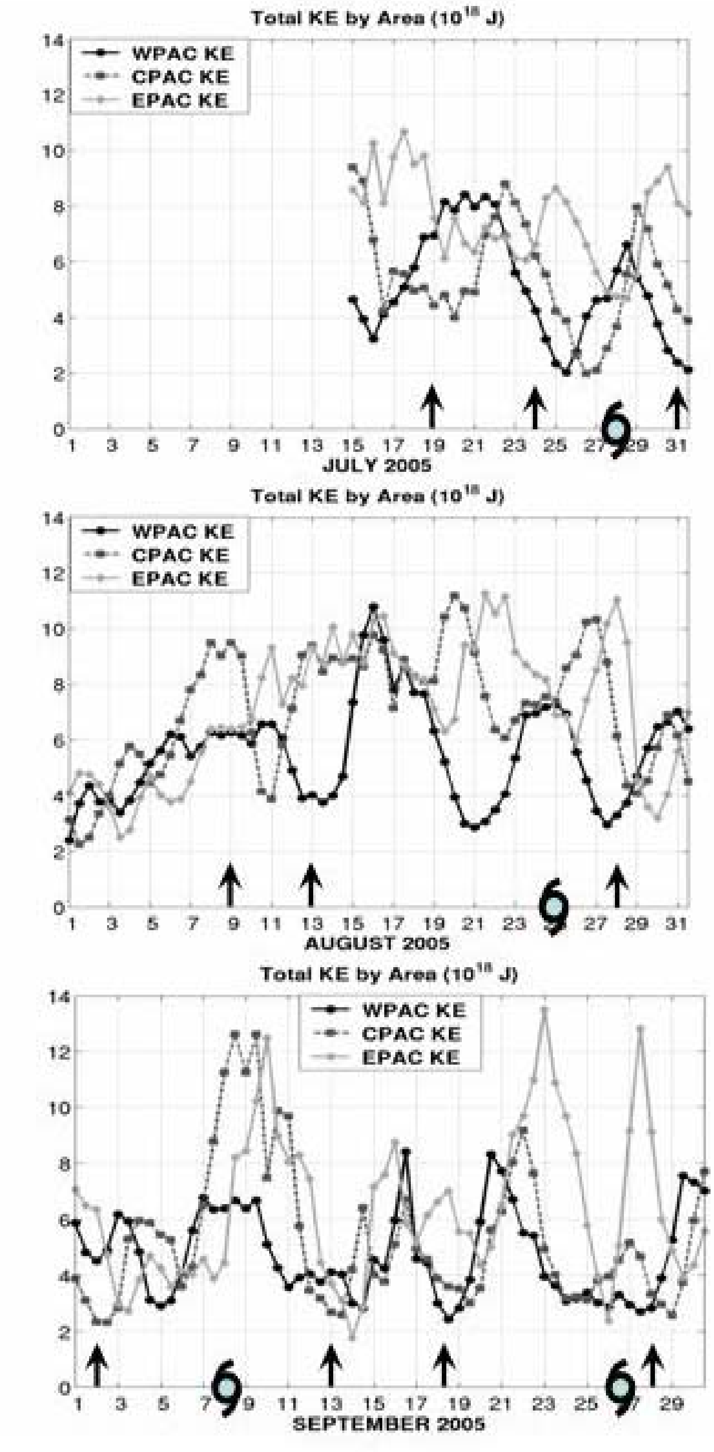

Figure 4: Volume integrated eddy kinetic energy (1018 J) over the North Pacific between 15 July – 30 September 2005. The tropical cyclone symbol marks the dates that tropical cyclones moved poleward of 40^{o}N. The arrows mark the last date associated with a tropical cyclone that stayed south of 40^{o}N.

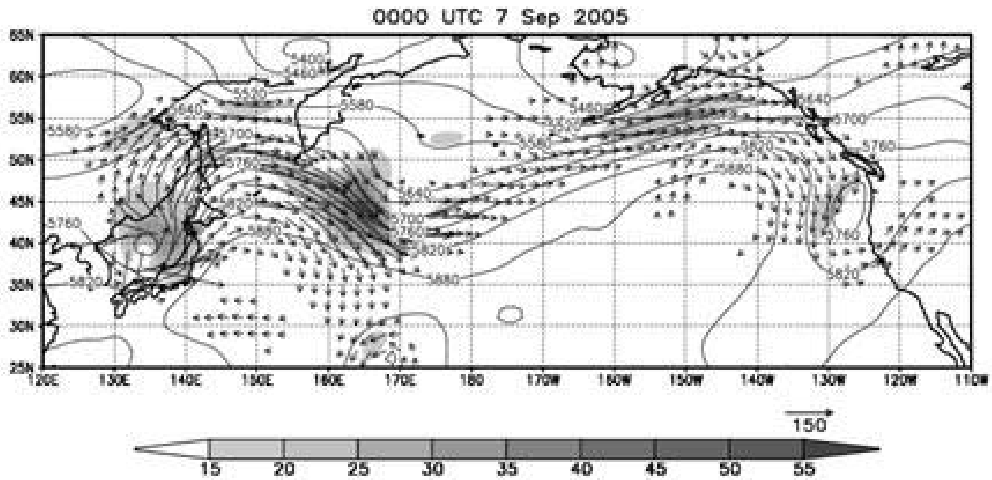

Figure 5: Vertically averaged eddy kinetic energy (shaded in units of 105 J m-2) at 0000 UTC 7 September 2005, Vectors define the energy flux (reference vector in lower right, units of 105 W m^{-1}), and contours are 500 hPa heights at 60 m intervals.

SUMMARY

Significant progress on important aspects of tropical cyclone formation, structure change, and extratropical transition has been made over the past year. The approach has been to examine important physical processes in a multi-scale framework. Several important results have direct bearing on shore- and sea-based fleet operations with respect to sortie and operation planning purposes.

REFERENCES

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